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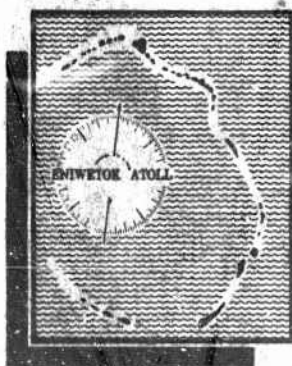
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Project 6.4a

WATER-WAVE MOTION PICTURES OVER SHALLOW WATER

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WATER-WAVE MOTION PICTURES
OVER SHALLOW WATER

By

William D. Baker, CDR, USN

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Los Alamos Scientific Laboratory
University of California
February 1953

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ABSTRACT

Motion pictures were taken of the waves produced by the Ivy Mike shot. They were taken over shallow water inside the lagoon near some of the islands of the atoll. Records were obtained at Elmer and Yvonne which give arrival times corresponding to an average wave velocity of about 80 ft/sec. The general character of the waves was a long slow rise followed by a long negative phase during which several smaller oscillations were observed. The complete wave train was not observed. The indicated product of wave amplitude (highest to lowest water) times the horizontal distance from zero was 4.5×10^5 sq ft. Since this value was increased by shoaling, the deep-water amplitude was somewhat less, and the product is estimated as 2.7×10^5 sq ft. The results are in agreement with theory, including the predictions of George N. White on the upper limit for the Mike water-wave amplitudes.

ABSTRACT

Motion pictures were taken of the waves produced by the Ivy Mike shot. They were taken over shallow water inside the lagoon near some of the islands of the atoll. Records were obtained at Elmer and Yvonne which give arrival times corresponding to an average wave velocity of about 80 ft/sec. The general character of the waves was a long slow rise followed by a long negative phase during which several smaller oscillations were observed. The complete wave train was not observed. The indicated product of wave amplitude (highest to lowest water) times the horizontal distance from zero was 4.5×10^5 sq ft. Since this value was increased by shoaling, the deep-water amplitude was somewhat less, and the product is estimated as 2.7×10^5 sq ft. The results are in agreement with theory, including the predictions of George N. White on the upper limit for the Mike water-wave amplitudes.

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

CHAPTER 1

OBJECTIVE

The purpose of Project 6.4a was to obtain a record of the action of the water waves produced inside the lagoon by the Ivy Mike shot as these waves approached and struck the beaches of four of the islands of the atoll. The type of record desired was a motion picture which would serve primarily as a documentary film of the event and which would be useful in planning future operations of a scale comparable to Mike shot. In addition, quantitative information regarding the time of arrival of the waves, their amplitude, and their duration was desired. This information could be compared with the existing theory concerning the scaling laws for explosions over water in the hope of extending the theory to even larger explosions. This quantitative information also would be useful for comparison with the records of Projects 6.4b, 6.7a, and 6.7b, which measured water waves using underwater pressure pickups.

CHAPTER 2

BACKGROUND

A theory for scaling large surface explosions in shallow water is contained in a study prepared by White.[1] This study shows, first of all, that exact scaling is not possible and that an approximation may be attempted only if the effects of gravity, surface tension, viscosity, and similar quantities are assumed to be negligible. It shows further that several choices of scaling laws are possible. A final choice of scaling laws is then made in the study. This choice is shown to be in good agreement with small-charge results and the Bikini Baker results. Finally, predictions are deduced for explosions in the megaton range.

A complete discussion of the limitations and assumptions of the theory is given in an interlaboratory report;[1] a few will be summarized here.

The method of scaling is first to find the ratio of the optimum depths for underwater explosions of the charges under consideration. The optimum depth is one for which the bubble formed in the explosion will just vent at the surface at maximum bubble time. The collapse of this bubble will then produce waves of maximum amplitude. The scaling law for finding the ratio is given as

$$\frac{W_1}{W_2} = \frac{h_1^3}{h_2^3} \frac{(h_1 + H_1)}{(h_2 + H_2)}$$

where h is the optimal charge depth, W is the charge weight, H is the atmospheric head on the surface, and the subscripts distinguish between the two explosions.

If W_1 is large and W_2 is small, then

$$h_1 \gg H_1 \qquad h_2 \ll H_2$$

and

$$\frac{h_1}{h_2} = \left(\frac{W_1}{W_2}\right)^{\frac{1}{4}} \left(\frac{H_2}{h_2}\right)^{\frac{1}{4}}$$

The assumption is then made, following Shapiro,[2] that the product of the amplitude, y (crest to trough), and range, r, scales like the ratio of optimal charge depths,

$$\frac{y_1 r_1}{y_2 r_2} = \frac{h_1}{h_2}$$

and, further, that this product scales like the water depth,

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$$\frac{y_1 r_1}{y_2 r_2} = \frac{d_1}{d_2}$$

Now the basic assumption is made that a surface explosion scales in the same manner as an underwater one at optimum depth.

These relations, applied to scaling small-charge results up to Bikini Baker, gave reasonably good agreement. Applied to larger explosions, they give the following result for 10 Mt with a depth of 180 ft:

$$yr = 6.55 \times 10^5 \text{ sq ft}$$

The observations described in this report will be compared with this result since 10 Mt, deduced from fireball measurements, appears to be the best yield determination for Mike shot at the time of writing.

It should be remembered that the theory leading to the foregoing result is based on a number of approximations and assumptions so that it is difficult to form an estimate of its reliability. In particular it should be noted that the theory applies to a surface burst over open water and therefore ought to be considered an upper limit for the wave amplitudes in the actual case considered here, where the explosion occurs on an island with a surrounding reef. Furthermore the effects of shoaling and the character of the bottom are not taken into account.

The effect of shoaling on water waves which enter shallow water from deeper water may be estimated by a method given in the Crossroads report by Revelle.[3] The energy in a wave is proportional to the wave length and the square of the amplitude. As the wave moves into shallow water, the wave length decreases by the same ratio as the velocity decreases. This ratio is the square root of the ratio of depths. To keep the energy in the wave constant requires the amplitude to increase by the fourth root of the inverse depth ratio:

$$\frac{y \text{ (deep water)}}{y \text{(shallow water)}} = \sqrt[4]{\frac{d \text{ (shallow water)}}{d \text{ (deep water)}}}$$

This Crossroads report also includes the records of the very complete water-wave observations made at Bikini in both deep and shallow water. The observations and theory are extremely useful.

The formation of breakers is treated in an article by Stoker,[4] which also includes a mathematical study of wave propagation in shallow water and the effect of sloping beaches. This article shows that waves approaching a beach will usually become sufficiently steep to break. Upon breaking, a further increase of amplitude will occur which will amount to 30 to 60 per cent. Of particular interest in this article is the demonstration that the propagation of water waves in shallow water is analogous to the propagation of pressure waves in gases. In this treatment, breakers are analogous to discontinuous shock in gases.

Standard references on water waves include Lamb[5] and Milne-Thomson.[6] For underwater explosions, Cole[7] may be consulted.

REFERENCES

1. George N. White, Study for Surface Explosions in Shallow Water, enclosure to Los Alamos Scientific Laboratory Memorandum J-9543 of Jan. 22, 1952, by E. J. Zadina.
2. Maurice M. Shapiro, Blast Waves, Los Alamos Scientific Laboratory Report LA-1023, Vol. VII, Chap. 15.
3. Roger Revelle, Report of the Co-ordinator of Oceanography, Enclosure F to Report of the Technical Director, Operation Crossroads. XR-156.

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4. J. J. Stoker, The Formation of Breakers and Bores, Communications on Applied Mathematics, 1(1): 1 (January 1948) with Appendix by K. O. Friedrichs, The Derivation of the Shallow Water Theory.
5. H. Lamb, "Hydrodynamics," Dover Publications, Inc., New York, 1945.
6. L. M. Milne-Thomson, "Theoretical Hydrodynamics," The Macmillan Co., New York, 1950.
7. R. H. Cole, "Underwater Explosions," Princeton University Press, Princeton, N. J.

CHAPTER 3

INSTRUMENTATION

Photography for Project 6.4a was done by Edgerton, Germeshausen & Grier, Inc. (EG&G). Four Eastman Kodak Cine Special 16-mm motion-picture cameras, fitted with normal (25-mm) focal-length lenses, were employed. These cameras were mounted in heavy lead-lined housings with the camera pointing vertically upward. A mirror on top of the housing redirected the line of sight horizontally. Cameras were installed at Station 303 on top of the EG&G timing station on Janet, at 305 near the shore line on Ursula, at 307 on the timing station near the airstrip on Yvonne, and at 302 on the north end of Elmer.

The cameras were loaded with 200 ft of Eastman Microfile film and were run by governor-controlled motors. It was intended that they should operate at 8 frames/sec, which would give about 17 min running time. However, it was found that a speed of 12 frames/sec was necessary for reliable starting. This reduced the running time to about 11 min. The cameras on Janet and Ursula were started by signals at −15 sec. Those on Yvonne and Elmer were started by mechanical timers at +10 and +21 min, respectively. These times were selected to bracket the expected wave-arrival times, as nearly as possible, between camera starting and stopping. Unfortunately, the shortening of the camera running time to 11 min on Ursula resulted in missing wave arrival there. It was believed by EG&G that the difficulty of inserting a delay timer at this station would jeopardize other more important photographic records.

In order to mark the surface of the water and facilitate quantitative observations, an array of objects was placed in the water in the field of view of each camera. A plot of the general arrangement used at each island is shown in Figs. 3.1 to 3.4.

The wooden beach poles were approximately 1 ft in diameter, marked alternately with 1-ft black and white stripes. The poles were anchored in concrete blocks set near the edge of the water where it was about 3 ft deep. These poles were used as markers for measuring the rise near the shore line and as convenient measuring scales for other measurements made on the films. The poles were located 300 ft in front of the cameras, except on Janet, where the distance was 600 ft and where a larger pole with 2-ft stripes was used. For a distance of 300 ft, the EG&G Photographic Plan for Ivy quotes a resolution of 0.4 ft at the target. This value is based on a resolution of 0.03 mm on the film. Figure 3.5 is a photograph of the pole at Elmer.

Beyond the poles, at a distance of 900 ft, an array of five oil barrels was moored. They were placed 30 ft apart on a line roughly perpendicular to the shore line. The barrels were painted white. A pad eye was welded to the barrel for securing the mooring wire. The drums were moored to concrete blocks using a scope equal to depth plus 15 ft except for depths greater than 15 ft, where a scope of twice the depth was used. These lengths of wire were selected to prevent a large wave from submerging the drums. The resolution for a distance of 900 ft is 1.2 ft. Figure 3.6 is a photograph of the array at Elmer.

To permit observations farther from the cameras and in deep water, rafts were moored at 3000 ft. Detailed drawings for these rafts are shown on Holmes and Narver (H&N) sheet

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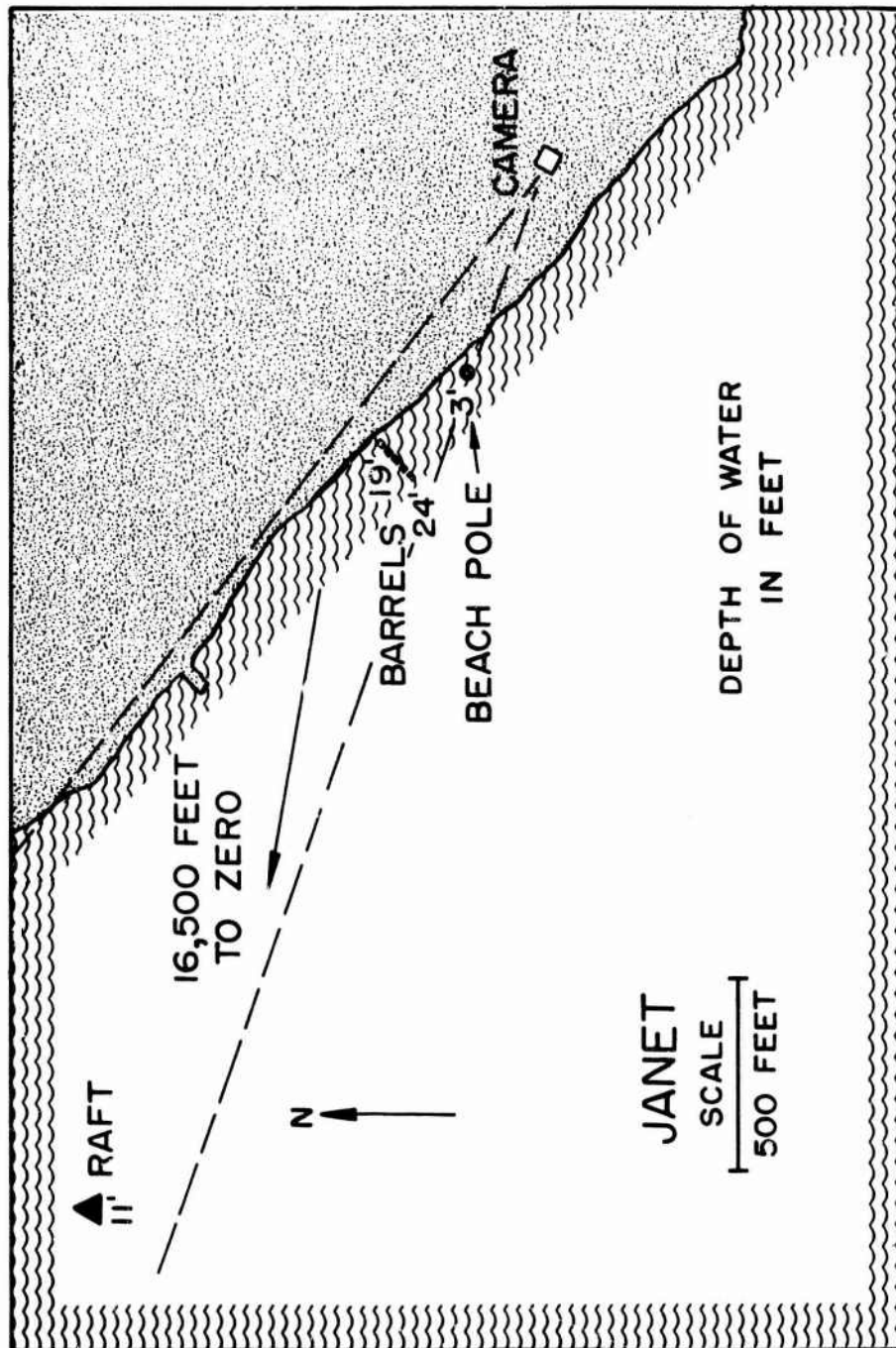Fig. 3.1—Chart showing the arrangement of water markers at Janet.
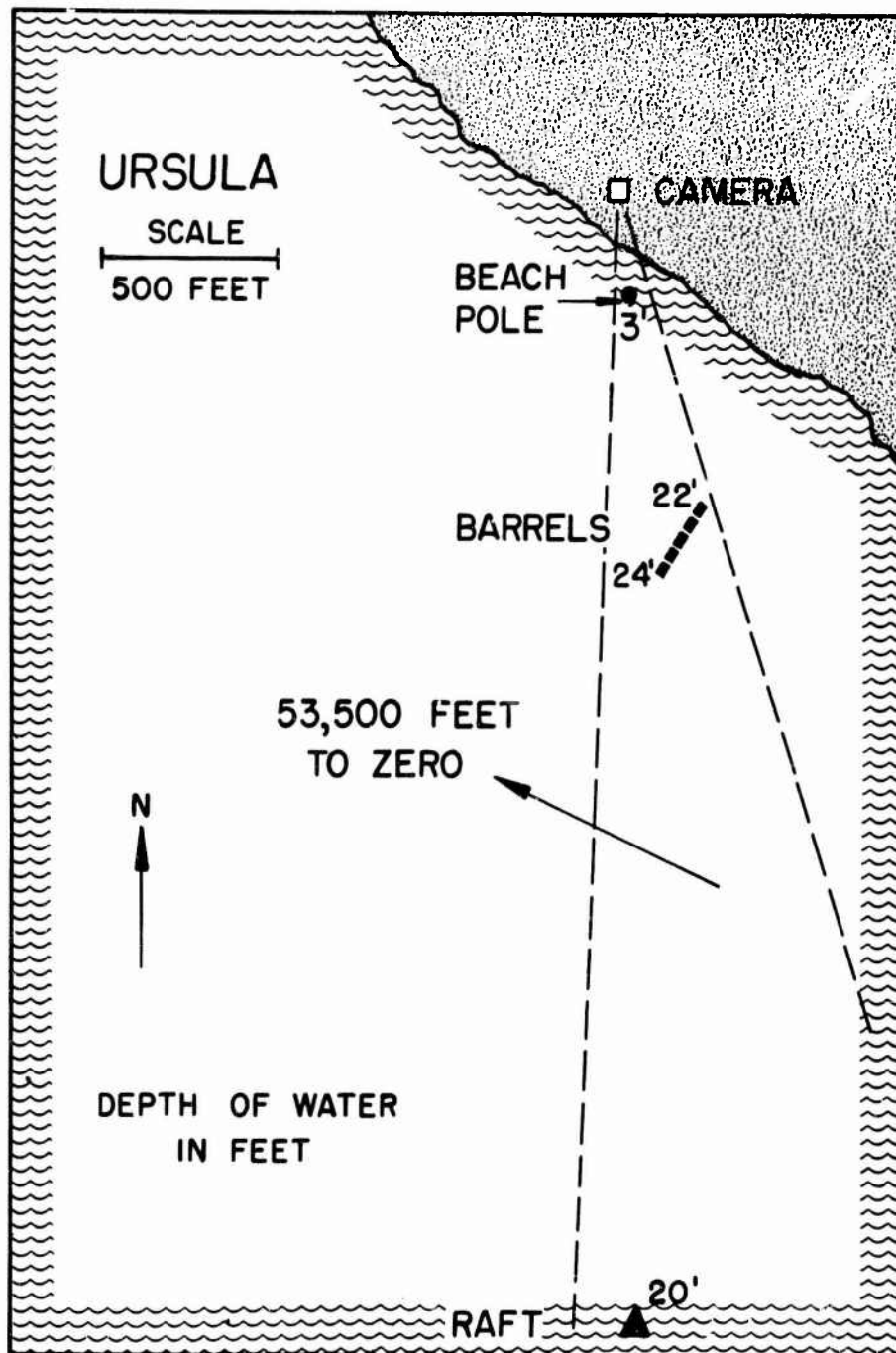
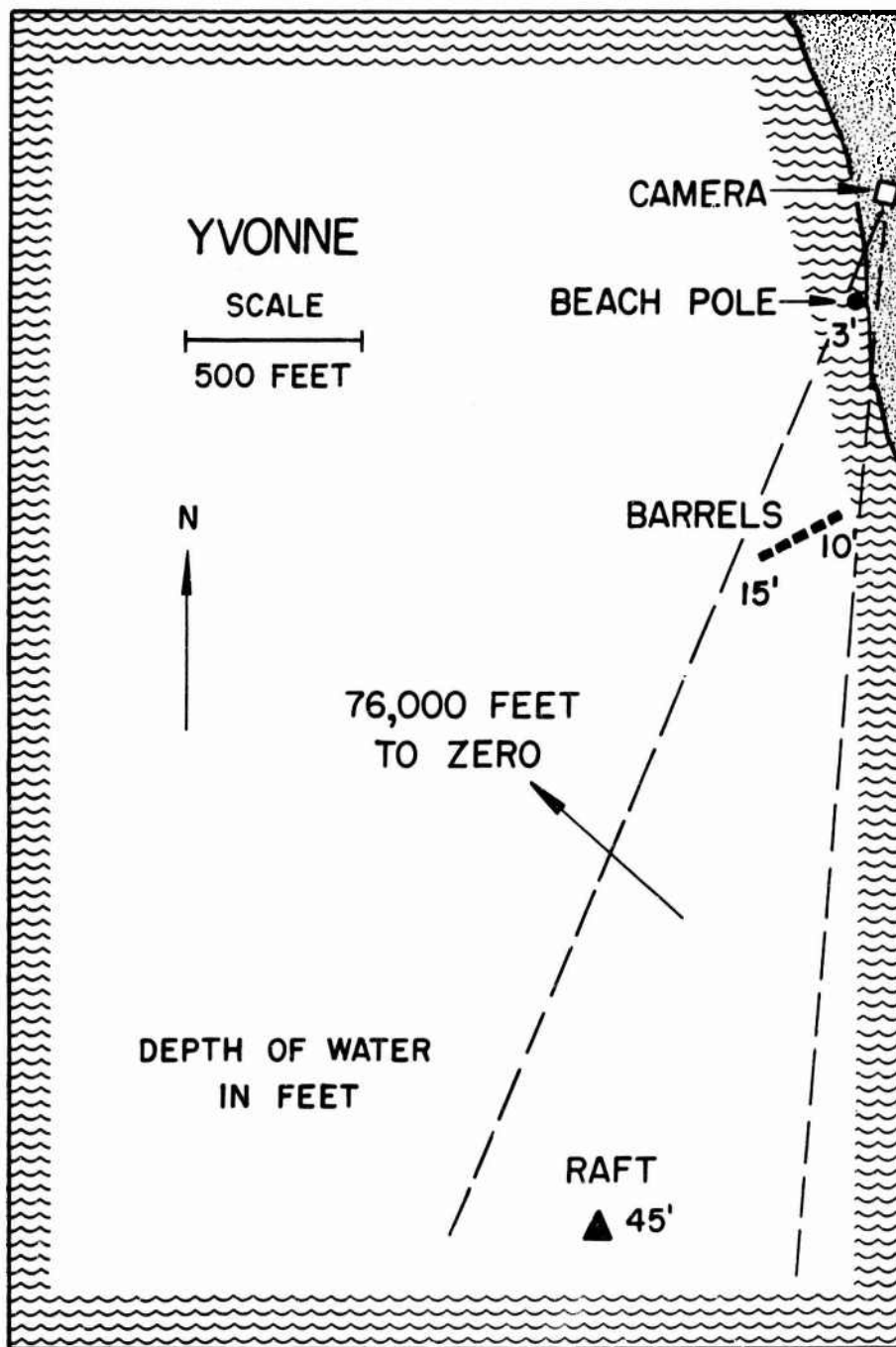Fig. 3.2—Chart showing the arrangement of water markers at Ursula.

Fig. 3.3—Chart showing the arrangement of water markers at Yvonne.

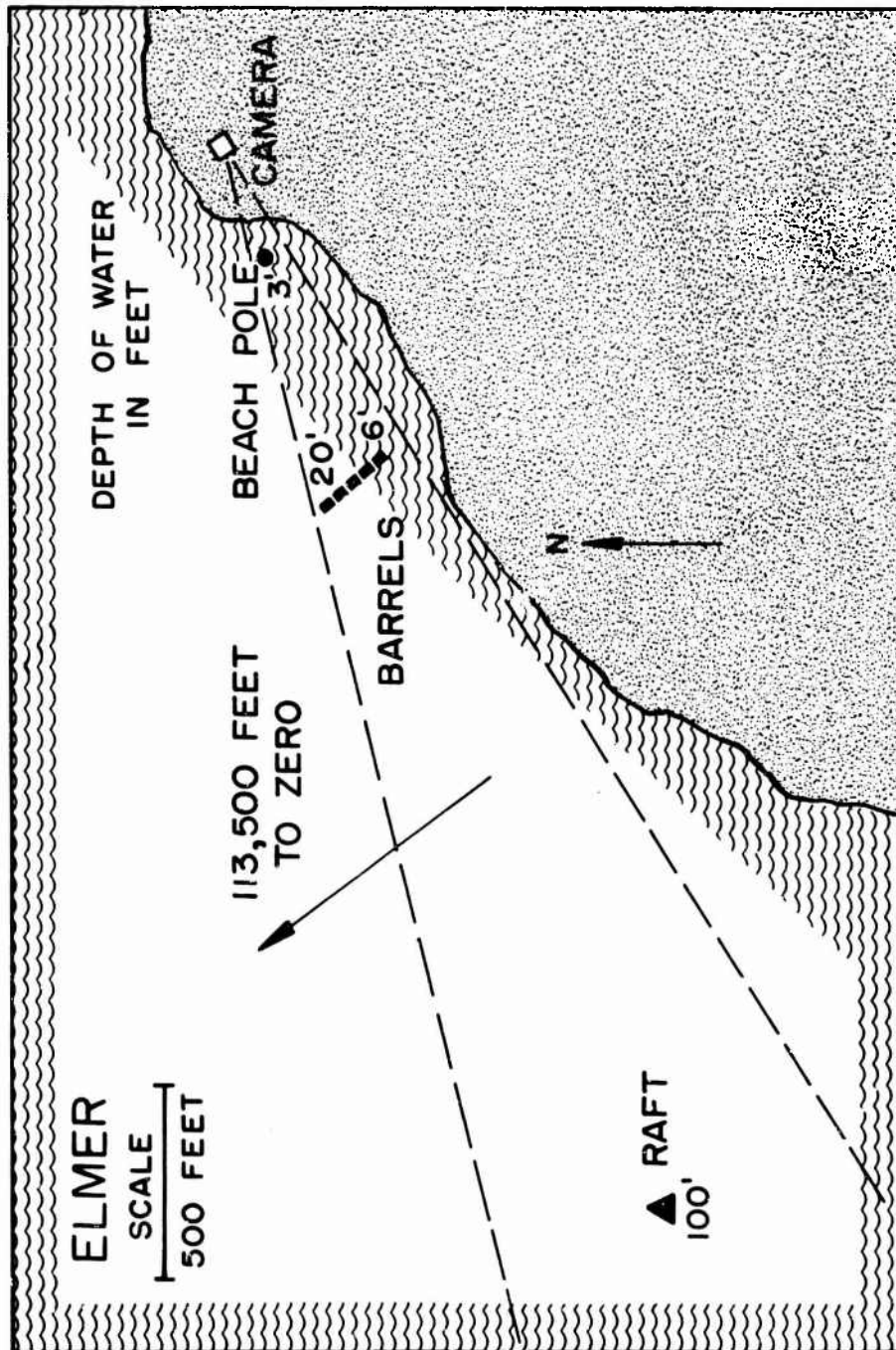Fig. 3.4 — Chart showing the arrangement of water markers at Elmer.

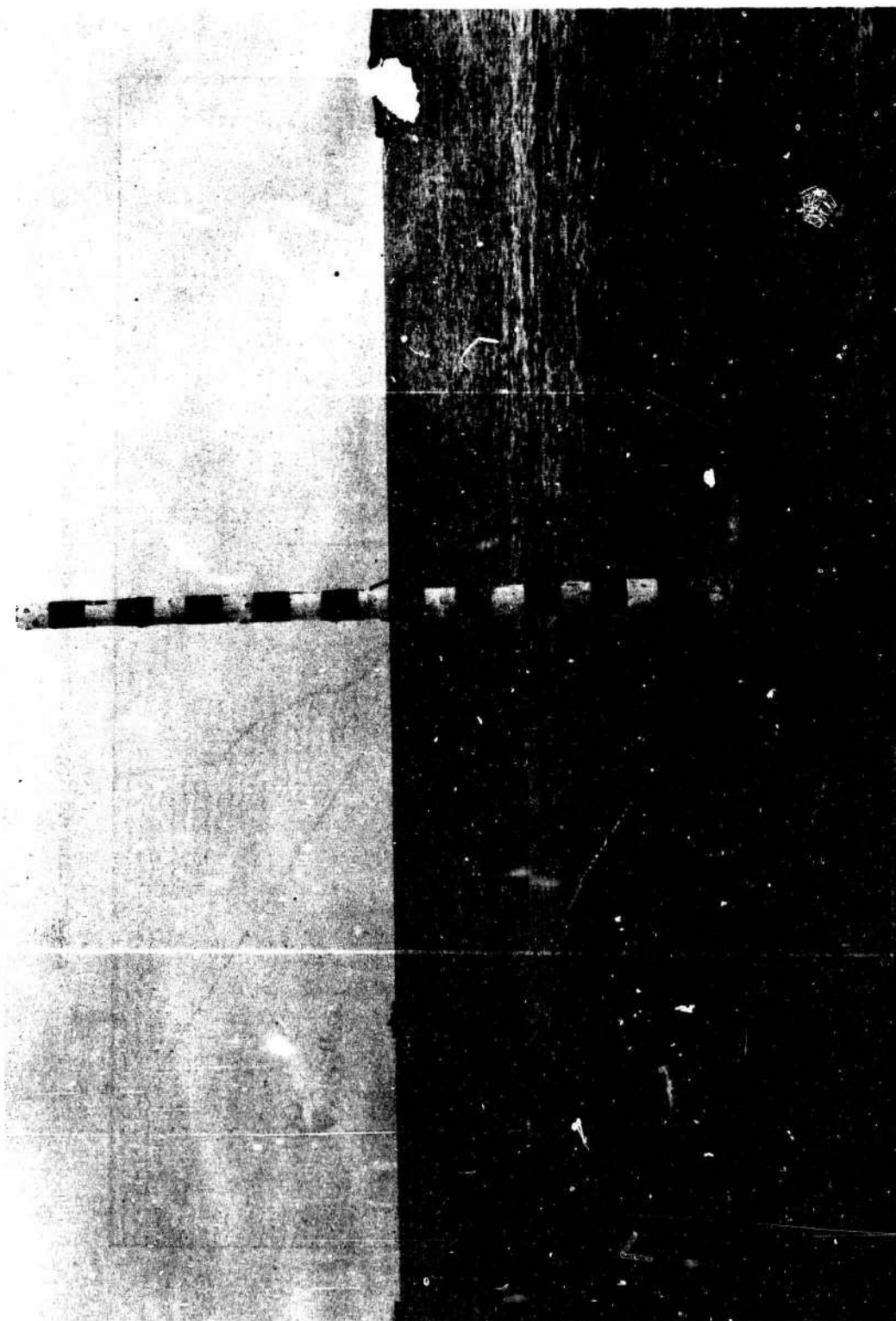RESTRICTED DATA — SECRET — SECURITY INFORMATION
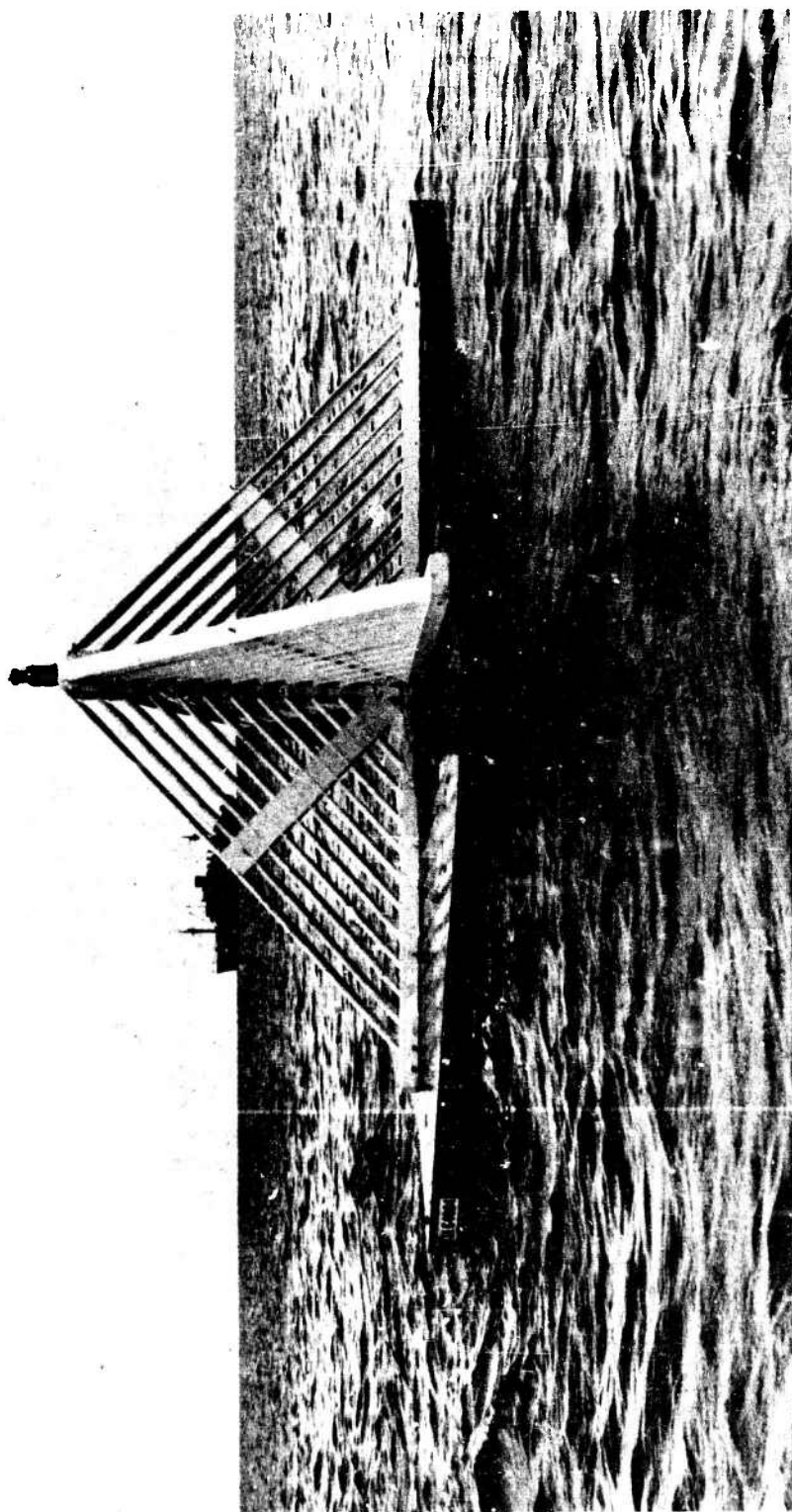
Fig. 3.5—Beach pole, Elmer.

Fig. 3.6—Barrel array. Elmer.

Fig. 3.7—Raft array, Elmer.

number 6163-Q-3, and Fig. 3.7 is a photograph of the raft array. The rafts were 15 by 25 ft. Each of them was supported by 26 oil drums, covered by 2-in. deck planking. A 4- by 4-in. vertical post, 10 ft high, was erected in the center of all rafts except the one at Janet. From each of the four sides of this center post, 45° diagonal slats extended to the deck. The whole formed a pyramidal structure as may be seen in the photograph. The open-slatted construction was chosen to reduce the dynamic pressure from the blast winds following the explosion.

At Janet, 16,500 ft from zero, peak overpressures of about 15 psi were expected. This static pressure is not particularly serious since the raft is quickly engulfed by the pressure field. However, associated with this peak pressure was a wind blowing for a considerable time, with a velocity of about 500 ft/sec, which produced a dynamic pressure of 5 psi on the upwind surfaces of the raft. This dynamic pressure necessitated the use of considerably more rugged construction for the raft at Janet. A 12- by 12-in. center post was used, and the diagonal slats were heavier and more strongly braced. For details, see the H&N drawing previously mentioned.

The rafts were moored with $\frac{1}{2}$-in. wire cable with a scope equal to twice the depth of the water. Northill 20R47 utility anchors were used. No difficulty from dragging anchors was encountered during preshot storms in which winds up to 40 knots were experienced; the slatted construction was probably helpful. On Mike –2 days a "weak link" in the form of a single bight of new $\frac{1}{2}$-in. diameter manila line was inserted between each raft and its wire mooring cable. This line had a breaking strength of 2650 lb. Since the rafts, when totally submerged, had an excess buoyancy of over 10,000 lb, waves large enough to submerge the rafts would have broken this link and permitted the rafts to continue their function of marking the surface of the water. As it resulted, none actually broke.

The resolution of the cameras for these 3000-ft targets was 4 ft.

The manufacture and installation of beach poles, barrels, and rafts were undertaken by H&N. The system was designed with the possibility of waves as high as 10 to 15 ft in mind, and it was considerably overdesigned, therefore, for the waves actually encountered.

The prints of the films obtained were first viewed by ordinary projection in order to observe the qualitative features of the waves. For quantitative measurements, single frames were examined with a Recordak projector, using a 20× magnification. Measurements were made on the projected image, using the markings on the beach poles as a scale of distances.

CHAPTER 4

RESULTS

Positive results were obtained at Yvonne and Elmer. On Janet the inclined mirror on top of the camera housing was destroyed by air blast. The record showed a view of the sky above the camera for 11 min following the shot. On Ursula, as noted in Chap. 3, the starting time was too early, and wave arrival was missed. The data are contained in EG&G film number 18014.

4.1 YVONNE

At Yvonne the camera started at +10 min. The film showed the usual waves caused by the wind. A few of these waves produced breakers very near the shore line. The displacements produced by these waves were small—less than a foot. The tide at this time was at about mean tide level, i.e., 2 ft above lowest low water. The depths shown in Figs. 3.1 to 3.4 are referred to mean tide level and thus represent conditions at arrival time. The surface wind was 12 knots from 110°. Figure 4.1 shows the undisturbed conditions. Arrival time at Yvonne was at 14 min and 20 sec after zero time. This corresponds to an average velocity of propagation of 88 ft/sec. The usual formula[1,2] for the velocity of waves in water having a depth that is small compared to the wave length is

$$c = \sqrt{g(d)}$$

where c is the propagation velocity, g is the acceleration of gravity, and d is the depth. For the average lagoon depth of 180 ft, this gives a velocity of 75 ft/sec. It appears that the waves traveled with a greater velocity than this for a considerable time, probably in the early stages of propagation.

The displacements produced by the waves are plotted in Fig. 4.2. The accuracy of the observations is indicated on the figure. At the pole the accuracy was limited to 0.5 ft by the camera resolution. At the barrels the limitation was 1 ft for camera resolution and 4 ft because the horizontal displacements of the barrels were not uniform. At least every sixtieth frame (5 sec) was examined. However, only significant changes are indicated, and these are by straight lines. Because the changes are slow and the space resolution is relatively poor, the time resolution is limited to about 10 sec.

At the beach there was first a rise lasting for about 50 sec, which increased the depth by 3 ft. Figure 4.3 shows this maximum. During the rise the barrels were also displaced upward by about 2 ft and shoreward by about 15 ft (the scope of their moorings). A horizontal motion of the raft of about 5 ft was also observed at this time. This initial wave did not break.

The water level then subsided, starting first at the barrels, where the level fell back to zero and somewhat later to −2 ft. At the beach the fall is relatively rapid — 5 ft in 20 sec (see Fig. 4.4). Small oscillations were observed until 150 sec after arrival time, when a breaker approached the beach in the vicinity of the pole. Because a sharp discontinuity could be seen, its
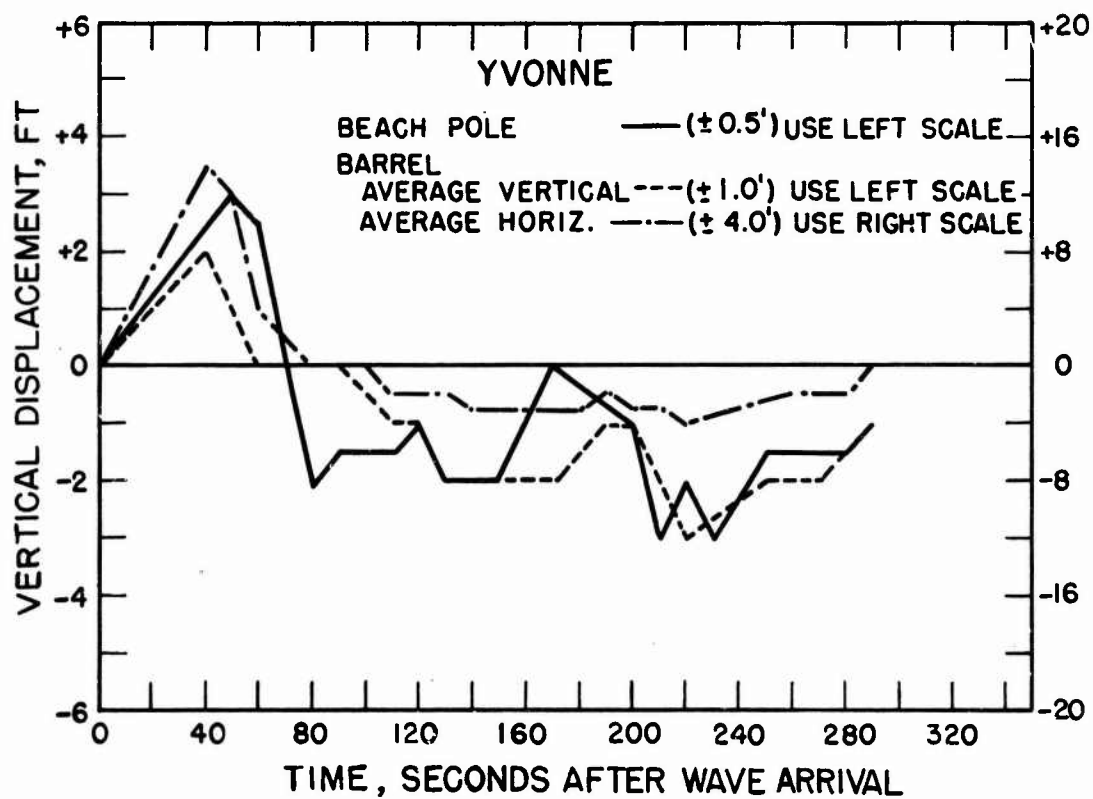
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Fig. 4.1—Undisturbed surface conditions at Yvonne.

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Fig. 4.2—Surface displacements, Yvonne.

Fig. 4.3—Maximum rise, 50 sec after arrival, Yvonne.

Fig. 4.4—First minimum, 80 sec after arrival, Yvonne.

velocity could be measured. It was found to be about 40 ft/sec. This velocity was considerably greater than might have been expected. Lamb[1] gives the following equation for the velocity of a bore or breaker advancing into still water:

$$c = g\left[\frac{d_1}{d_0} \frac{(d_1 + d_0)}{2}\right]$$

where d_0 is the depth of the still water and d_1 is the depth behind the discontinuity.

From this equation the velocity of advance would be estimated as about 20 ft/sec for the depths in this vicinity and for a discontinuity of no more than 2 ft. It may be that the breaker was advancing into water which was already flowing back toward the beach after the first minimum and that the velocities are superimposed.

The breaker may be seen in Fig. 4.5 as it strikes the shore line. The spray appears dark on the figure. At this time, 170 sec after arrival, the water level at the beach pole was back to normal. The same disturbance passed over the barrels about 20 sec later and caused a smaller vertical displacement, which gave evidence that the character of the waves was strongly influenced by the nature of the bottom.

The water level again fell, reaching a low of −3 ft by 210 sec, when the base of the beach pole was momentarily exposed. The level at the barrels fell to about the same value. Figure 4.6 shows this phase and also a local breaker near the beach to the left of the pole.

At 230 sec a slow rise began, and by the end of the film, at 280 sec, the level was only slightly below normal, as shown by Fig. 4.7.

The horizontal motions of the barrels were in phase with the vertical motions during the period of the observation. After the first fall the horizontal motion was fairly small, less than 4 ft on the average. The outermost barrel executed somewhat larger horizontal motions than the others. Horizontal motion of the raft was also observed. It coincided with the motion of the barrels. A shoreward motion of about 5 ft accompanied the initial rise. The raft then moved about 10 or 12 ft seaward and remained there during the rest of the time. The vertical motion of the raft was less than 4 ft, the resolving power of the system.

4.2 ELMER

At Elmer the camera started at +21 min. The initial appearance of the surface was similar to that described for Yvonne. Figure 4.8 shows the undisturbed conditions.

Arrival time at Elmer occurred at 24 min and 30 sec after zero time and was signalized by a slow shoreward motion of the barrels. The time of arrival corresponded to an average velocity of 78 ft/sec, again slightly higher than would be estimated from the depth of the lagoon. The two arrival times are plotted on log-log paper in Fig. 4.9. The slope of the line joining them is 0.8.

The average barrel displacements are shown in Fig. 4.10, and the discussion of Fig. 4.2 applies here also, except that after time 200 sec the horizontal motions of the individual barrels frequently differed by as much as 10 ft from the plotted average.

Vertical displacement was observed after about 60 sec, and it reached a height of about 2.5 ft at 130 sec.

The level then fell to −2 ft. This phase is shown in Fig. 4.11. At time 210 sec the water level was raised about 2 ft by a wave which formed a breaker. It may be seen as a dark front in Fig. 4.12. The velocity of this breaker was measured at about 10 ft/sec, which is less than would be estimated from the calculation previously described. This wave was probably meeting a strong undertow or outflow of water which would hasten the breaking action but would slow down the advance of the resulting breaker, as is described by Stoker.[3]

This wave subsided and was followed by another higher one which did not break The level was again falling when the film ended. More waves would probably have been observed had the camera run longer.

Fig. 4.5—Breaker on the shore, 170 sec after arrival, Yvonne.

Fig. 4.6—Second minimum, 210 sec after arrival, Yvonne.

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Fig. 4.7—Final appearance, 280 sec after arrival, Yvonne.

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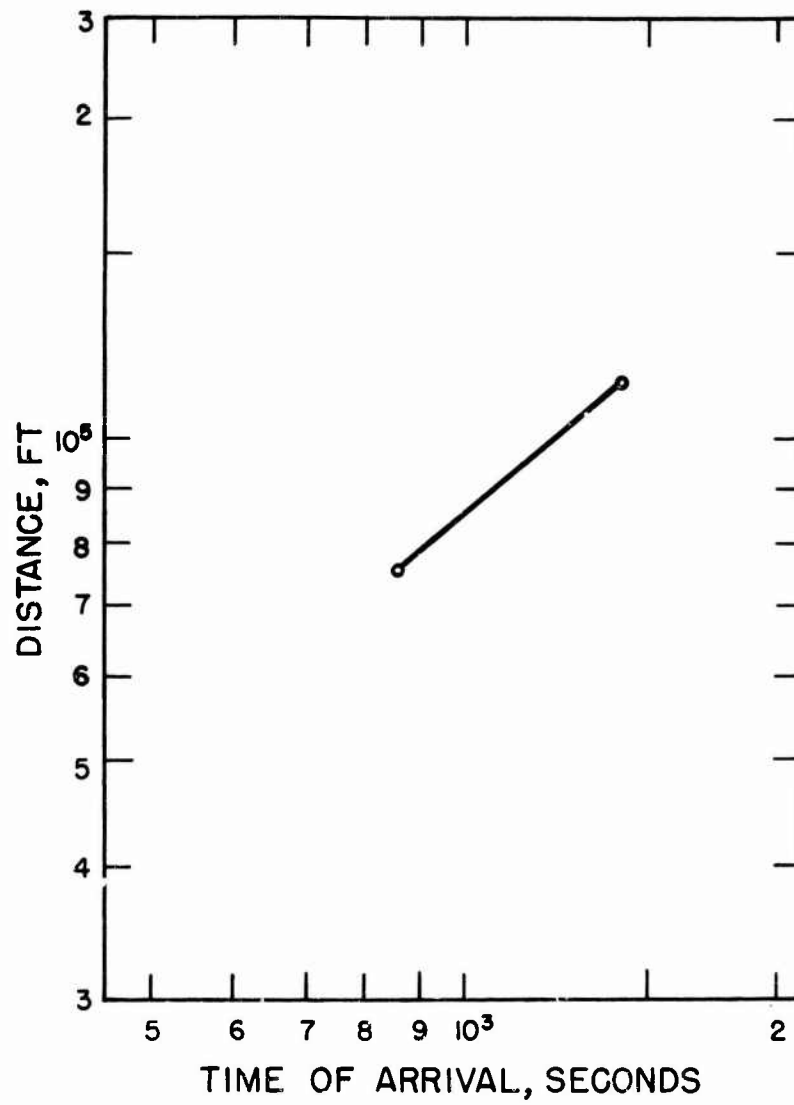
Fig. 4.8—Undisturbed surface conditions at Elmer.
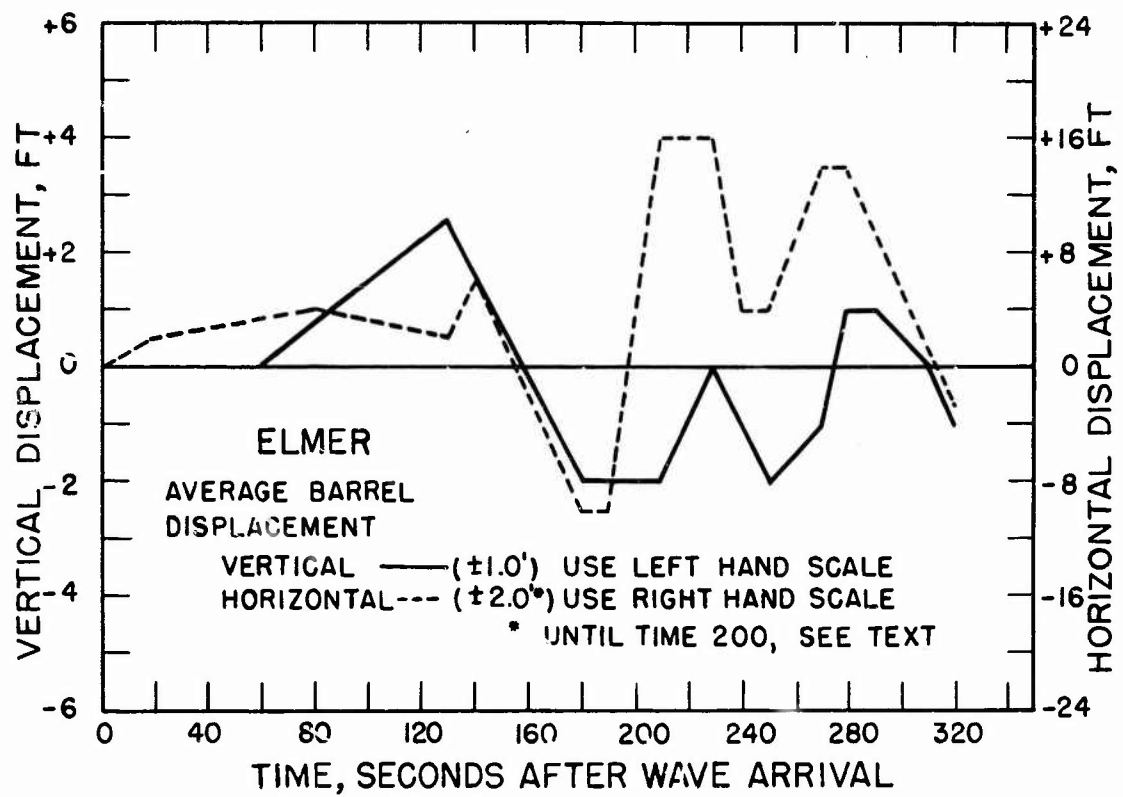
Fig. 4.9—Time-of-arrival, Yvonne and Elmer.

Fig. 4.10—Surface displacements, Elmer.

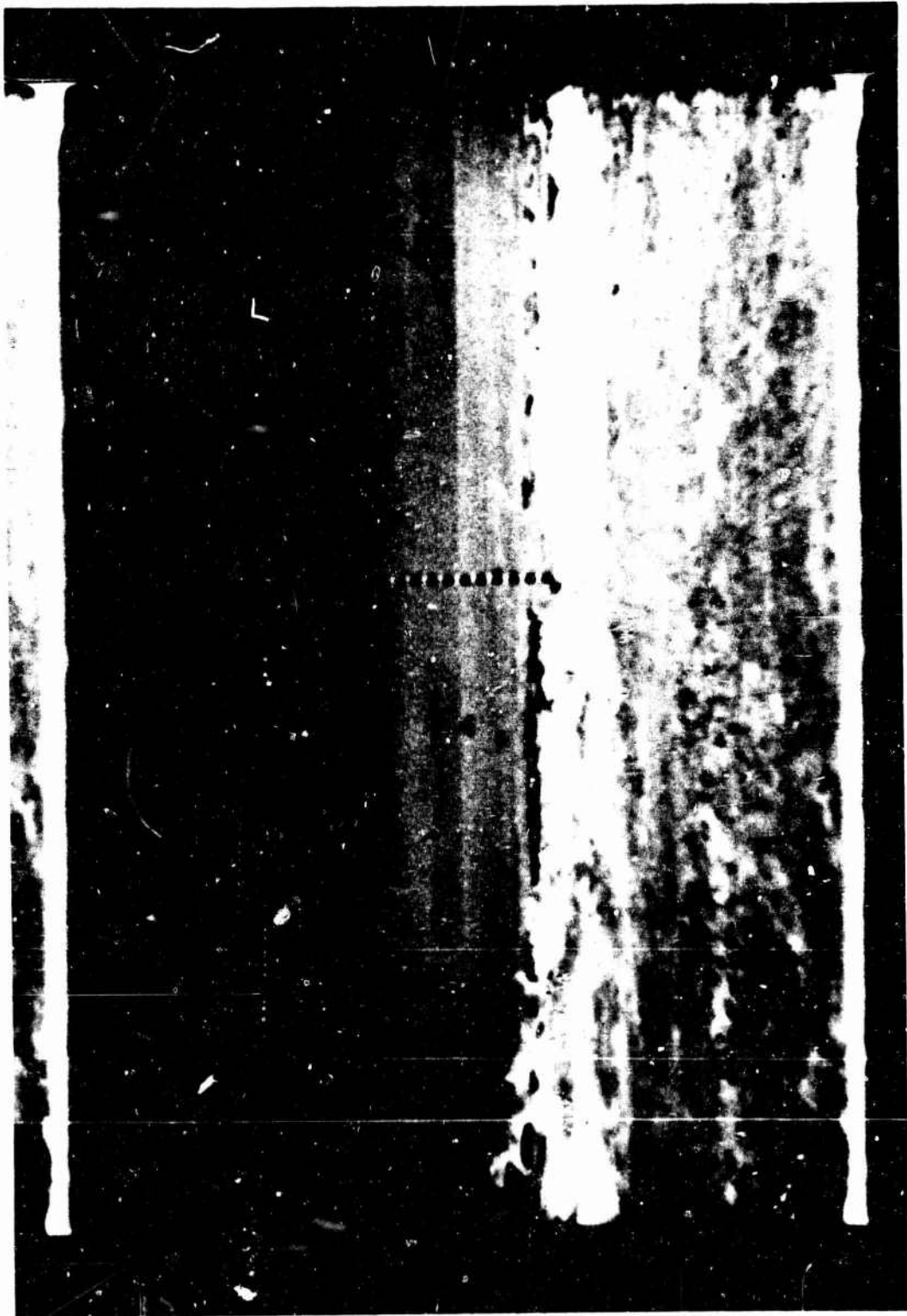Fig. 4.11—First negative phase, 180 sec after arrival, Elmer.

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Fig. 4.12—Breaker. 210 sec after arrival, Elmer.

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Fig. 4.13—Final appearance, 320 sec after arrival, Elmer.

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The horizontal motions accompanying these waves were perceptible before the vertical motions. These horizontal motions were larger than at Yvonne, probably because of different bottom conditions. During the latter stages of the observaticn, after time 200 sec, the horizontal displacements of the barrels differed at certain times by as much as 10 ft, although all were generally synchronized in time and direction.

Horizontal motion of the raft was also observed. It too was larger than at Yvonne, amounting to about 20 ft in the positive direction followed by 5 ft in the negative. The disturbance appeared to arrive at the raft a few seconds before it arrived at the barrels, although lack of resolution makes this uncertain. The vertical motion of the raft was less than the 4-ft resolution of the system. The appearance of the water at the end of the film is shown in Fig. 4.13.

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1. H. Lamb, "Hydrodynamics," Dover Publications, Inc., New York, 1945.
2. L. M. Milne-Thomson, "Theoretical Hydrodynamics," The Macmillan Co., New York, 1950.
3. J. J. Stoker, The Formation of Breakers and Bores, Communications on Applied Mathematics, 1(1): 1 (January 1948) with Appendix by K. O. Friedrichs on The Derivation of the Shallow Water Theory.

CHAPTER 5

DISCUSSION

The general appearance of the waves may be summarized as follows: There was first a long solitary positive pulse. This is similar to the description of the Bikini Baker waves by Revelle.[1] From the observed durations and the calculated velocities, the length of the initial positive pulse in deep water may be estimated as of the order of 5000 ft. This pulse was followed by a general lowering of the water level below normal. Following this, a few waves of varying amplitude and period were seen. The characteristics of these waves were strongly affected by the local conditions of the bottom. Wave velocities in shallow water decrease with decreasing depth, and therefore a wave approaching a shore line is always subject to such phenomena as refraction, interference, and dispersion. As a result the height, duration, phase relations, and other characteristics of the waves at any location depend more strongly on the nature of the bottom than on any other circumstance.

The figure showing times of arrival, Fig. 4.9, can be represented by the equation

$$r \approx 300t^{0.8}$$

where r is the radial distance from zero in feet and t is the time of arrival in seconds. This equation indicates that the velocity of the waves was initially higher than the 75 ft/sec calculated from the water depth and that it decreased to a value lower than this for distances greater than 75,000 ft.

Motion pictures taken from Janet for Project 6.2 (Air Mass Motion) showed the air shock traveling across the water, accompanied by a water disturbance at the foot of the shock. The velocity of this early disturbance would be high, of course—of the order of 1500 to 2000 ft/sec. At distances greater than 75,000 ft, the wave begins to encounter shoals and reefs north of Elmer which would slow the advance.

Considering only the maximum crests and troughs, the observations indicated the following values for the product of the shallow-water wave amplitude y and distance r:

$$yr \text{ (Yvonne)} \approx 6 \times 75,000 \approx 4.5 \times 10^5 \text{ sq ft}$$
$$yr \text{ (Elmer)} \approx 4 \times 113,000 \approx 4.5 \times 10^5 \text{ sq ft}$$

The deep-water amplitude may be estimated by a method given by Revelle[1] and summarized in Chap. 2, for which the final result is

$$\frac{y \text{ (deep water)}}{y \text{ (shallow water)}} = \sqrt{\frac{d \text{ (shallow water)}}{d \text{ (deep water)}}}$$

For depths of 180 and 20 ft, this gives a ratio of 0.6, and

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yr (deep water) $\approx 2.7 \times 10^5$ sq ft

This indicates that the methods of scaling used by White[2] were successful in predicting an upper limit for the magnitude of the waves. This is particularly true when it is remembered that the presence of the island and reef near ground zero was expected to reduce the predicted values. It also indicates that a wave of the order of 15 ft may have been produced at Janet. Such a wave might very well have inundated the island. The evidence of displaced poles and coral rock observed on Janet after the shot tended to indicate that water may have surged a considerable distance inshore. However, a strong blast wave crossed the island; so the evidence is not conclusive.

If the cameras had run for a longer time, it seems likely that more waves would have been observed. The appearance of the Elmer record suggests this. At Bikini Baker several crests and troughs were observed. Some of the later waves at Bikini were actually larger than the first, the explanation being that the group (energy) velocity of the wave train is less than the phase velocity, and thus the point of maximum height may move backward in the train.

The duration and accuracy of the observations do not justify an attempt to integrate the energy in the waves. Judging from the Bikini Baker calculations, it may have been a few tenths of a per cent of the total bomb energy, probably even less since the coupling was poorer.

REFERENCES

1. Roger Revelle, Report of the Co-ordinator of Oceanography, Enclosure F to Report of the Technical Director, Operation Crossroads, XR-156.
2. George N. White, Study for Surface Explosions in Shallow Water, enclosure to Los Alamos Scientific Laboratory Memorandum J-9543 of Jan. 22, 1952, by E. J. Zadina.

CHAPTER 6

RECOMMENDATIONS

As a result of the experience at Operation Ivy, specific recommendations may be made as follows:

1. The mirror on top of the camera housing should be strengthened at close stations to avoid the loss of records such as occurred at Janet.

2. Camera motors with more reliable starting should be employed. Longer periods of time could be observed, and 8 frames/sec is more than ample for good time resolution.

3. Good reliance can be placed in time-of-arrival and wave-amplitude predictions. Cameras need not be started so long before arrival as was done on this project. The raft installation could have been omitted. The beach poles could have been smaller.

4. White 16-mm motion pictures are satisfactory for the documentary type of record desired in this case; detailed observations with high resolution would require larger cameras and a much more elaborate photographic system. Such a system was successfully employed at Bikini, and it is described in the report by Revelle.[1]

5. Shallow-water waves are strongly dependent on the local character of the bottom. For comparisons between observations and theory, deep-water records would be more useful.

REFERENCE

1. Roger Revelle, Report of the Co-ordinator of Oceanography, Enclosure F to Report of the Technical Director, Operation Crossroads, XR-156.

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MEMORANDUM FOR DISTRIBUTION

SUBJECT: Declassification Review of Operation IVY Test
            Reports

The following 31 (WT) reports concerning the atmospheric
nuclear tests conducted during Operation IVY in 1952 have been
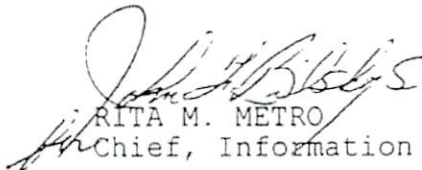declassified and cleared for open publication/public release:

WT-602 through WT-607, WT-609 thru WT-618, WT-627 thru WT-
631, WT-633, WT-635, WT-636, WT-639, WT-641 thru WT-644, WT-646,
and WT-649.

An additional 2 WTs from IVY have been re-issued with
deletions. They are:

WT-608, WT-647.

These reissued documents are identified with an "Ex" after
the WT number. They are unclassified and approved for open
publication.

This memorandum supersedes the Defense Nuclear Agency, ISTS
memorandum same subject dated August 17, 1995 and may be cited as
the authority to declassify copies of any of the reports listed
in the first paragraph above.

RITA M. METRO
Chief, Information Security